6 Management Measure for Vegetated Treatment Systems

This chapter presents supporting information, including management practices, specific implementation examples, and costs and benefits, for the following management measure:

> **Management Measure**
>
> **Promote the use of engineered vegetated treatment systems such as constructed wetlands or vegetated filter strips where these systems will serve a significant NPS pollution abatement function.**

This management measure is intended to be applied in cases where engineered systems of wetlands or vegetated treatment systems can treat NPS pollution. Vegetated treatment systems (VTS) are located in upland regions and protect wetlands and aquatic resources from NPS pollution.

Vegetated treatment systems, by definition in this guidance, include vegetated filter strips (VFS) and constructed wetlands. Although these systems are distinctly different, both are designed to reduce NPS pollution. They need to be properly designed, correctly installed, and diligently maintained to function properly. The two types of VTS are discussed in more detail in separate sections below.

Whether constructed wetlands and VFS should be used individually or in series depends on several factors, including the quantity and quality of the inflowing runoff, the characteristics of the existing hydrology, and the physical limitations of the area surrounding the wetland or riparian area to be protected.

Vegetated Filter Strips

The purpose of VFS is to remove sediment and other pollutants from runoff and wastewater by filtration, deposition, infiltration, absorption, adsorption, decomposition, and volatilization, thereby reducing the amount of pollution entering surface waters (USDA, 1988). Vegetated filter strips are appropriate for use in areas adjacent to surface water systems that may receive runoff containing sediment, suspended solids, and/or nutrients. Vegetated filter strips can improve water quality by removing nutrients, sediment, suspended solids, and pesticides; however, they are most effective in removing of sediment and other suspended solids.

Vegetated filter strips are designed to be used under conditions in which runoff passes over the vegetation in a uniform sheet flow. Sheet flow is critical to the success of the filter strip. If runoff is allowed to concentrate or channelize, the VFS is easily inundated and will not function as designed.

VFS can improve water quality by removing nutrients, sediment, suspended solids, and pesticides.

Vegetated filter strips need the following elements to work properly (Schueler, 1987; see Figure 6-1):

- A device such as a level spreader that ensures that runoff reaches the VFS as sheet flow. (Berms can be used for this purpose if they are placed at a perpendicular angle to the VFS area to prevent concentrated flows.)
- A dense vegetative cover of erosion-resistant plant species.
- A gentle slope of no more than 5 percent.
- A length at least as long as the adjacent contributing area.

In addition to serving as a pollution control measure, VFS can add positive improvements to the urban environment by increasing wildlife habitat and adding beauty to an area.

If these requirements are met, VFS have been shown to remove a high percentage of particulate pollutants. The effectiveness of VFS at removing soluble pollutants is highly variable (Schueler et al., 1992).

Several studies of VFS (Table 6-1) show that they improve water quality and can be an effective management practice for the control of NPS pollution from silvicultural, urban, construction, and agricultural sources of sediment, phosphorus, and pathogenic bacteria. The research results reported in Table 6-1 show that VFS are most effective at sediment removal, with rates generally greater than 70 percent. The published results on the effectiveness of VFS in nutrient removal are more variable, but nitrogen and phosphorus removal rates are typically greater than 50 percent.

The following are nonpoint pollution sources for which VFS might provide some nutrient-removal capability:

- *Cropland.* The primary function of grass filter strips is to filter sediment from soil erosion and sediment-borne nutrients. However, filter strips should not be relied on as the sole or primary means of preventing nutrient movement from cropland (Lanier, 1990).
- *Urban development.* Vegetated filter strips filter and remove sediment, organic material, and trace metals. According to the Metropolitan Washington Council of Governments, VFS have a low to moderate ability to remove dissolved pollutants in urban runoff and have higher efficiency for removal of particulate pollutants than for removal of soluble pollutants (Schueler, 1987).

With proper planning and maintenance, VFS can be a beneficial part of a network of NPS pollution control measures for a particular site. They can help to reduce the polluting effects of agricultural runoff when coupled with either (1) farming practices that reduce nutrient inputs or minimize soil erosion or (2) detention ponds that collect runoff as it leaves a VFS. Properly planned VFS can add to urban settings by framing small streams, ponds, or lakes, or by delineating impervious areas.

Constructed Wetlands

Constructed wetlands are typically engineered systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist, at least partially, in treating an effluent or other source of water (Figure 6-2). These systems should be engineered and constructed in uplands, outside "waters of the United States," unless the water source can serve a significant restoration function for a degraded system. For example, agricultural runoff could potentially be directed toward a wetland that has been degraded due to water withdrawal in order to both treat the runoff and restore the hydrology of the wetland. In such cases, it is important that the runoff not contain contaminants that could pose a threat to people or wildlife. Properly designed and implemented constructed wetlands can be effective tools for improving water quality while also providing a range of other benefits, such as wildlife habitat. According to Hammer and others (1989), constructed wetlands typically have four principal components that can assist in pollutant removal:

- Substrates with various rates of hydraulic conductivity
- Plants adapted to water-saturated anaerobic substrate
- A water column (water flowing through or above the substrate)
- Aerobic and anaerobic microbial populations.

Moshiri (1993), Kent (1994), Kadlec and Knight (1996), the Washington State Department of Ecology (1992), and USEPA (1996a) present design and maintenance criteria for constructed wetlands. Davis (1996) has developed a series of handbooks addressing general considerations for wetland construction and criteria for constructing wetlands for various treatment scenarios, including storm water management.

Constructed wetlands have been considered for use in urban and agricultural settings where some sort of engineered system is suitable for NPS pollution reduction. A few studies have also been conducted to evaluate the effectiveness of artificial wetlands that were designed and constructed specifically to remove pollutants from surface water runoff (Table 6-2).

Table 6-2 summarizes the pollutant-removal effectiveness of constructed wetland systems built for treatment of surface water runoff. In general, constructed wetland systems designed for treatment of NPS pollution in surface water runoff were effective at removing suspended solids and pollutants that attach to solids and soil particles. The constructed wetland systems were not as effective at removing dissolved pollutants and those pollutants that dissolve under the conditions found in a wetland.

Like VFS, constructed wetlands offer an alternative to other structural NPS pollution control systems. In some cases, constructed wetland systems can provide limited ecological benefits in addition to their NPS control functions. In other cases, constructed wetlands offer few, if any, additional ecological benefits because of the type of vegetation planted in the constructed wetland or because of the quantity and type of pollutants received in runoff. Constructed wetlands that receive water containing large amounts of metals or pesticides should be fenced or otherwise designed to discourage use by wildlife.

Key Resources for Vegetated Treatment Systems

A Handbook of Constructed Wetlands. 1996. L. Davis. Volumes 1-5. Prepared for the USDA-Natural Resources Conservation Service and USEPA Region 3, in cooperation with the Pennsylvania Department of Environmental Resources. Available from Government Printing Office.

Buffer Zones: Their Processes and Potential in Water Protection. Proceedings of the International Conference on Buffer Zones, September 1996. N.E. Haycock, T.P.Burt, K.W.T. Goulding, and G. Pinay. Quest Environmental, Harpenden, Herts, UK.

Constructed Wetlands for Water Quality Improvement. 1993. G.A. Moshiri, CRC Press, Inc. Boca Raton, FL.

Constructed Wetlands for Wastewater Treatment and Wildlife Habitat. 1993. U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC. EPA832-R-93-005.

Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. 1988. D.A. Hammer, ed. Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers, Inc., Chelsea, MI.

Created and Natural Wetlands for Controlling Nonpoint Source Pollution. 1993. CRC Press, Inc., Boca Raton, FL.

Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid-Atlantic Region. 1992. T.R. Schueler, Metropolitan Washington Council of Governments, Washington, DC.

Evaluation and Management of Highway Runoff Water Quality. 1995. G. K. Young, S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. U.S. Department of Transportation, Federal Highway Administration. Publication No. FHWA-PD-96-032.

Relative Nutrient Requirements of Plants Suitable for Riparian Vegetated Buffer Strips. 1996. R.C. Steiner, Interstate Commission on the Potomac River.

Treatment Wetlands. 1996. R.H. Kadlec, and R.L. Knight. CRC Press, Inc. Boca Raton, FL.

Vegetated Stream Riparian Zones: Their Effects on Stream Nutrients, Sediments, and Toxic Substances. 1997. An annotated and indexed bibliography. D. Correll. Smithsonian Environmental Research Center, Edgewater, MD.

6.1 Management Practices for Vegetated Treatment Systems

The management measure generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The two practices listed below can be applied successfully to implement the management measure for vegetated treatment systems. The following pages provide details about each practice.

- Vegetated Filter Strips
- Constructed Wetlands

6.1.1 Vegetated Filter Strips Factors to Consider

Practice

Construct vegetated filter strips in upland areas adjacent to water bodies that may be subject to suspended solids and/or nutrient runoff.

A survey of the literature on the design, performance, and effectiveness of VFS shows that many factors must be considered on a site-specific basis before designing and constructing a vegetated filter strip. The effectiveness of VFS varies with topography, drainage size, vegetative cover, implementation, and use with other management practices. In addition, different VFS characteristics such as size and type of vegetation can result in different pollutant loading characteristics, as well as loading reductions. Table 6-1 and Table 6-3 give some removal rates for specific NPS pollutants based on VFS size and vegetation.

Vegetated filter strips have been successfully used in a variety of situations where some sort of BMP was needed to treat surface water runoff. Typical locations of VFS have included the following:

- Below cropland or other fields
- Above conservation practices such as terraces or diversions
- Between fields
- Alternating between wider bands of row crops
- Adjacent to wetlands, streams, ponds, or lakes
- Along roadways, parking lots, or other impervious areas
- In areas requiring filter strips as part of a waste management system
- On forested land

Vegetated filter strips function properly only in situations where they can accept overland sheet flow of runoff and should be designed accordingly. Contact time between runoff and the vegetation is a critical variable influencing VFS effectiveness. If existing site conditions include concentrated flows, BMPs other than VFS should be used. Pollutant-removal effectiveness increases as the ratio of VFS area to contributing area increases.

Schueler (1992), the Washington State Department of Ecology (1992), and USEPA (1996a) present design and maintenance criteria for VFS. Forested riparian buffer strips are a variation of standard VFS designs. A forested riparian buffer strip consists of an area of trees and/or shrubs located adjacent to and upslope from water bodies (USDA, 1995). When appropriately designed and managed, these buffer strips can contribute significantly to the maintenance of aquatic and riparian habitat. Additional discussion and design criteria for forested buffer strips are presented in USDA (1995) and Belt et al. (1992).

Several key local elements should be considered in the design of VFS: type of pollutant, slope, length, climate, plant species, detention time, monitoring, and maintenance.

Type of Pollutant

Sediment, nitrogen, phosphorus, and toxic substances are efficiently removed by VFS although removal rates are much lower for soluble nutrients and toxics (see Table 6-3). Monitoring should be conducted to determine the effectiveness of VFS in pollutant reduction and to determine if the VFS are meeting performance standards (water quality standards or prescribed VFS removal efficiency criteria).

Slope

VFS function best on slopes of less than 5 percent; slopes greater than 15 percent render them ineffective because surface runoff flow will not be sheet-like and uniform. The effectiveness of VFS is strongly site-dependent. They are ineffective on hilly plots or in terrain that allows concentrated flows.

Length

The length of VFS is an important variable influencing their effectiveness because the contact time between runoff and vegetation in the VFS increases with increasing VFS length. Some sources recommend a minimum length of about 50 feet (Dillaha et al., 1989a; Nieswand et al., 1989; Schueler, 1987). USDA (1988) has prepared design criteria for VFS that take into consideration the nature of the source area for the runoff and the slope of the terrain. Another suggested design criterion in the literature is for the VFS to be at least as long as the runoff-contributing area. Unfortunately, there are no clear guidelines available in the literature for calculating VFS lengths for specific site conditions. Accordingly, this guidance does not prescribe a numeric value for the minimum length for an effective filter strip or a standard method to be used in the design criteria for computing the length of a VFS. Table 6-3 provides examples of nitrate-N reduction in surface waters and groundwater by VFS of various lengths at several locations in the United States and Europe.

VFSMOD

VFSMOD is a field-scale, storm-based model designed to calculate the outflow, infiltration, and sediment-trapping efficiency of VFS. The model uses time-dependent hyetograhs, space-distributed filter parameters (vegetation roughness or density, slope, and infiltration characteristics), and sediment characteristics to calculate VFS efficiency.

Source: Munoz-Carpena and Parsons, 1997.

Climate

Several regional differences are important to note when considering the use of VFS. Climate plays an important role in the effectiveness of these systems. The amount and duration of rainfall, the seasonal differences in precipitation patterns, and the type of vegetation suitable for local climatic conditions are examples of regional variables that can affect the performance of VFS. VFS should not be used in regions that have permafrost because infiltration is extremely limited, which greatly decreases the effectiveness of the BMP (USEPA, 1997b). Soil type and land use practices also vary with region and will affect characteristics of surface water runoff and thus of VFS performance. The sites where published research has been conducted on VFS effectiveness for pollutant removal are overwhelmingly located in the eastern United States. There is a demonstrated need for more studies located in different geographic areas in order to better categorize the effects of regional differences on the effectiveness of VFS.

Native Plants

The best vegetative species for VFS are those which will produce dense growths of grasses and legumes resistant to overland flow. Use native plants to avoid negatively affecting adjacent natural areas.

Detention

In the design process for a VFS, some consideration should be given to increasing the detention time of runoff as it passes over the VFS. One possibility is to design the VFS to include small rills that run parallel to the leading edge of the filter strip. These rills would trap water as runoff passes through the VFS. Another possibility is to plant crops upslope of the VFS in rows running parallel to the leading edge. Data from a study by Young and others (1980), in which corn was planted in rows parallel to the leading edge of the filter strip, show an increase in sediment trapping and nutrient removal.

Monitoring

The design, placement, and maintenance of VFS are all critical to their effectiveness, and concentrated flows should be prevented. Although intentional planting and naturalization of the vegetation will enhance the effectiveness of a larger filter strip, the strip should be inspected periodically to determine whether concentrated flows are bypassing or overwhelming the VFS, particularly around the perimeter. Regular inspection should be performed to determine whether sediment is accumulating within the VFS in quantities that would reduce its effectiveness (Magette et al., 1989). Monitoring should be conducted to determine the efficiency of VFS in pollutant reduction and to determine whether they are meeting performance standards.

Maintenance

For VFS that are relatively short in length, natural vegetative succession is not intended and the vegetation should be managed like a lawn. It should be mowed two or three times a year, fertilized, and weeded in an attempt to achieve dense, hearty vegetation. The goal is to increase the density of the vegetation to obtain maximum filtration. For wooded filter strips, maintenance is minimal, and gradual succession from grass to meadow to second-growth forest will enhance, rather than detract from, the performance of longer filter strips. This process can be enhanced by intentional landscape planting to facilitate vegetative succession. Corrective action is still necessary around the edge of the strip, and trees might help to prevent concentrated flows from forming (USDOT, 1996). In cold regions where deicers are used regularly during winter months, requirements specific to the region are usually necessary. Use of salt-tolerant plant species could be necessary where parking lot or roadway runoff is directed to the VFS. Maintenance activities following spring snowmelt should include maintenance and replacement of any salt-damaged vegetation. In addition, mulching might be required in the spring to restore soil structure and moisture capacity because deicing salts can damage soil structure and reduce the organic content of the soil (USEPA, 1997b). Consider including one or more of the following items in a VFS maintenance program to make the performance of any VFS more efficient:

- Adding a stone trench to spread water effectively across the surface of the filter.
- Keeping the VFS carefully shaped to ensure sheet flow.
- Inspecting for damage following major storm events.
- Removing any accumulated sediment.

All filter strips should be inspected on an annual basis and examined for gully erosion, vegetative density and health, concentrated flows, and damage from foot or vehicle traffic. Additional inspections should be conducted after high-volume runoff events. The flow spreader should be inspected to ensure that trash and debris have not collected in the spreader. Accumulated sediments should be removed to maintain sheet flow and preserve the original grade. Maintaining soil permeability is also crucial to ensure proper functioning of VFS. This might require periodic removal of thatch or mechanical aeration. Grass filter strips should be reseeded in dead or damaged areas where necessary, and dead vegetation in wooded filter strips should be removed (USDOT, 1996).

6.1.2 Constructed Wetlands

Practice

Construct properly engineered systems of wetlands for NPS pollution control. Manage these systems to avoid negative impacts on surrounding ecosystems or groundwater.

Siting Constructed Wetlands

The Interagency Workgroup on Constructed Wetlands has issued a guidance document entitled *Guiding Principles for Constructed Treatment Wetlands: Providing Water Quality and Wildlife Habitat* (USEPA, 2000a). The workgroup consists of representatives from the Environmental Protection Agency, Army Corps of Engineers, Fish and Wildlife Service, Natural Resources Conservation Service, National Marine Fisheries Service, and Bureau of Reclamation. The workgroup suggests the following considerations for siting constructed wetlands.

Constructed wetlands must be managed to avoid any negative impacts on wildlife and surrounding areas.

1. *Waters of the United States and Floodplains.* Constructed wetlands should generally be constructed in upland areas and away from floodplains.
2. *Opportunities for Restoration of Degraded or Former Wetlands.* Constructed wetlands should be built in existing or former wetlands only if the water entering the project meets water quality standards; the project will have a net environmental benefit; and the project will help restore the historical condition of the wetland.
3. *Watershed Considerations.* Consider the role of the constructed wetland in the watershed. Some issues to evaluate are water quality impacts, surrounding and upstream land uses, location relative to flyways or wildlife corridors, and public acceptance and perceptions.
4. *Water-Depleted and Effluent-Dependent Ecosystems*. Constructed wetlands may provide valuable ecological benefits in regions where water resources are limited because of climatic conditions (for example arid areas) and human-induced impacts (for example urban areas).

5. *Other Site Selection Factors.* Numerous factors can affect whether a particular site is appropriate for the development of a constructed wetland. These factors include

- Substrate or soils
- Hydrology/geomorphology
- Vegetation
- Presence of endangered species
- Socioeconomic impacts/issues
- Zoning considerations
- Health and safety issues.

The most important variable in constructed wetland design is hydrology. If proper hydrologic conditions are developed, the chemical and biological conditions will, to a degree, respond accordingly (Mitsch and Gosselink, 1993). The underlying soils in a wetland are key to establishing the proper hydrology. Soils vary in their ability to support vegetation, to prevent percolation of surface water into the groundwater, and to provide active exchange sites for adsorption of constituents like phosphorus and metals.

Design Considerations

The planning and design of a constructed wetland must include considerations for the quality of the influent, the types of pretreatment are necessary, and the shape and size necessary to accomplish the desired treatment. The Interagency Workgroup on Constructed Wetlands (2000) recommends that the following guidelines be considered in the design of constructed wetland systems.

1. *Minimal Impact.* Adverse impacts on waters of the United States should be avoided. Examples of impacts to be avoided include changes in hydrology, disruption of the composition and diversity of plant and animal communities, and degradation of water quality.
2. *Natural Structure*. Whenever possible, use soft structures, sinuous lines, and bioengineering practices in constructed wetlands design. Natural landscape formations, native vegetation, and gravity should be used to their best advantage.
3. *Buffer Zones.* Constructed wetlands should be surrounded by buffers or transition zones. These areas can also be used in the design as open space or wildlife corridors.
4. *Vector Control.* Facilities should be designed to minimize stagnant water as a precaution against mosquito problems. Biological control measures can also employed (e.g., purple martins, mosquito fish, bats).
5. *Hazing and Exclusion Devices.* In constructed wetlands where the water quality could present a significant threat to the health of wildlife, hazing or wildlife exclusion devices should be used. Examples include fencing, netting, and noise-makers.
6. *Dedicated Water Source.* A dedicated water supply should be available for the life of the constructed wetland and preferably longer. The water supply should be sufficient to maintain the wetland in times of drought. It

is important that the water supply for adjacent waterways not be negatively impacted as well.

7. *Biological Diversity and Physical Heterogeneity.* If possible, constructed wetlands should be designed to maximize species diversity native species. There are several guides for the selection of wetland plants; see Table 5-1 for a list of resources. To achieve this goal of diversity, it might be necessary to provide for physical heterogeneity in the facility design. Some examples of physical heterogeneity include having both surface and subsurface flow as well as some open areas of water, and designing islands for waterfowl nesting as well as buffer or upland areas for other bird species.

   The types of vegetation used in constructed wetlands depend on region and climate (Mitsch, 1977). For example, emergent wetlands are usually characterized by herbaceous vegetation, while eastern riparian wetlands are generally forested wetlands. When possible, use native plant species to avoid negative impacts on nearby natural wetland areas. Plants should be selected based on their ability to withstand fluctuating water levels. Hydrophytic plant species are the most suitable wetland plant. In coastal areas, the plants should be adapted to fluctuating salinity levels. There are several guides for the selection of wetland plants such as *Aquatic and Wetland Vascular Plans of the Northern Great Plains* (USDA, 1993), the Florida Department of Environmental Regulation's list of suggested wetland species (see Table 5-3), or the U.S. Fish and Wildlife Service's *National List of Plant Species that Occur in Wetlands* (http://www.nwi.fws.gov/bha).

8. *Seasonality and Capacity Exceedances.* Planners should consider extreme meteorological events and how exceedances of storage and treatment capacity will affect the facility.

9. *Forebays.* Constructed wetlands should contain sediment collection/settling forebays to trap sediment before runoff enters the vegetated area of the constructed wetland. Baffles and diversions should be strategically placed to prevent trapped sediment from becoming resuspended during subsequent storm events prior to cleanout. These components should be designed for ease of maintenance and removal of sediments. Appropriate upland disposal sites that meet applicable regulatory requirements should also be identified.

10. *Multiple Cells.* The benefits of using multiple treatment cells should be considered. Multiple cells can allow for greater flexibility in the operation and maintenance of constructed facilities, as well as potentially providing better treatment than single-cell systems.

11. *Maintenance Access.* Safe and easy access to the facility for personnel and vehicles is important for proper operation and maintenance with a minimum of disturbance.

12. *Public Acceptance.* Planners should take into consideration how the public perceives the facility. Mosquitoes, odors, and safety issues are common questions raised by the public. Engaging the community early in the project development process can help in gaining support and apprival

13. *Public Use.* Public access to constructed wetlands might or might not be appropriate depending on the intended purpose of the facility. If safety and health concerns are not an issue, designers may wish to develop educational displays for the facility to encourage better understanding of constructed wetlands and their many benefits.
14. *Pilot Projects and Design Criteria*. Pilot projects might be necessary to assist in designing full-scale projects. When pilot projects are not used, the design considerations should be fully described and documented for future reference.

The Kesterson National Wildlife Refuge in California is an excellent example of a case in which selenium contamination in wetland sediments was found to cause deaths and deformities in visiting waterfowl. Source: Ohlendorf et al., 1986.

PREWet
A screening level PC-based mathematical model (PREWet) is available for making pollutant removal estimates for wetlands. PREWet assumes steady-state conditions and either fully mixed or one-dimensional longitudinally varying concentrations to allow rapid model implementation with minimal input data requirements. Given basic wetland characteristics and the pollutants of concern, PREWet estimates the amount of pollutant treatment provided by the wetland.
Source: USACE, 1997.

Constructing and Maintaining Constructed Wetlands

The following guidelines should be considered during the active construction and operation phases of a constructed wetland.

1. *Construction Practices/Specification/Drawings.* The construction site should be properly evaluated prior to construction to ensure its suitability; proper engineering drawings should be used to clearly convey the design specification; and damage to surrounding land should be minimized by limiting excavation and surface runoff from the site. It is also important to note that a Clean Water Act section 402 permit may be required depending on the size of the project.
2. *Soils.* Soils used in the wetland should be carefully evaluated to match their permeability and other physical properties to the objectives of the project. The use of soils that may contain the seeds of unwanted plant species or unwanted contaminants should be avoided.
3. *Vegetation Selection.* Plant species should be chosen for their abilities to adapt to the water, soil, and light conditions of the constructed wetland. A variety of native species is preferable; the use of weedy or invasive species should be avoided. There are several guides for the selection of wetland plants; see Table 5-3 for a list of resources.
4. *Management Plan.* Develop a long-term plan for the maintenance, operation, funding, and monitoring of the constructed wetland. This plan should outline the routine maintenance activities required for proper operation and specify the person or group responsible for caring for the wetland.

5. *Regular Inspections and Maintenance Activities*. Operators should inspect the constructed wetland as necessary depending on the site and design. The inspection criteria and frequency should be described in the maintenance plan. Examples of maintenance activities include checking weir settings and inlet and outlet structures, cleaning surfaces that have solids or floatables accumulating on them, removing nuisance species, maintaining vegetation, and removing sediment from forebays.
6. *Operator Training.* Operators should be trained in the proper maintenance and operation of the wetland. State regulatory agencies, as well as some public or private training centers, may be able to assist with this training.
7. *Contingency Plan.* A contingency plan should address problems that may develop during the lifetime of the wetland due to construction or operation errors and unpredictable events. The plan might also include instructions for dealing with potential nuisance conditions.

There are many challenges as well as benefits for farmers installing and maintaining vegetative buffers, as described in the February 1999 NRCS publication, The National Conservation Buffer Initiative: A Qualitative Evaluation*. <http://www.nhq.nrcs.usda.gov/CCS/BuffQual.pdf>*

6.2 Costs and Benefits of Practices

This section describes the economic costs and benefits of creating vegetated treatment systems to control nonpoint sources of pollution. This information is intended to demonstrate the cost savings accrued by implementing the management measure as compared to the costs of not implementing it. Because of regional diversity, no single cost or economic benefit can be applicable across the United States. Instead, the information provided below and in Table 6-4 are examples of such costs and benefits in specific areas of the country.

The use of appropriate practices for pretreatment of runoff and prevention of adverse impacts on wetlands and other waterbodies involves the design and installation of vegetated treatment systems such as VFS or constructed wetlands, or the use of structures such as detention or retention basins. These types of systems are discussed individually elsewhere in this guidance document. The purpose of VTS is to remove, to the extent practicable, excessive levels of NPS pollutants and to minimize the impacts of hydrologic changes. Both VFS and constructed wetlands can function to reduce levels of pollutants in runoff or attenuate runoff volume before the runoff enters a natural wetland or riparian area or another water body.

One of the largest proponents of vegetative buffers through its National Conservation Buffer Initiative, is the USDA's Natural Resources Conservation Service or NRCS (see Appendix A). The National Conservation Buffer Initiative has the formal goal of installing 2 million miles of buffers by the year 2002. To date, approximately 619,000 acres, or nearly 172,000 miles, of buffers have been established under the Conservation Reserve Program continuous sign-up (NRCS, 2000a). Additional conservation buffers are being installed through other programs.

Most of the buffer development is focused on farmland. There are many challenges associated with the buffer program. For example, coordinators find it difficult to get buffers installed on rented land. Landlords are reluctant to forego the rent on that land, yet tenants have no guarantee that they will benefit from proposed buffers. Farmers have also voiced concerns about the program's low rental rates and about the restrictions it places on the use (haying, grazing) of buffers. The NRCS is addressing these issues along with educating the public on the benefits of buffers.

The costs for establishing of multispecies riparian buffer strip systems have been estimated at $358 to $396 per acre, and annual maintenance costs are estimated at $20 per acre. The establishment and maintenance costs do not include any existing governmental cost-share or other subsidy. Currently, there are several cost-share programs available that will cover up to 75 percent of the expenses (USEPA, 1996a).

Constructed wetlands are finding increasing uses in residential areas because they cost less than conventional wastewater treatment plants. They can be readily accommodated in areas that have the land such systems require. However, urban areas are also expressing a growing interest.

The town of Jerome, Arizona, recently chose to construct a wetland rather than build a mechanical treatment plant to treat its wastewater. Maintenance of the mechanical treatment plant was to cost about $1,000 per month, whereas maintaining the wetland was expected to cost "little or nothing." The city of Sierra Vista, Arizona, has partnered with the U.S. Bureau of Reclamation on a constructed wetland project that is expected to demonstrate the technology's environmental benefits. Such benefits would derive from using treated wastewater for aquifer recharge and for release directly to the river (University of Arizona, 1999).

The city of Des Moines, Washington, is using Clean Water Act State Revolving Fund (CW-SRF) funds to purchase and reconstruct a badly degraded wetland area and to construct a sediment trap/pond facility. The wetlands serve the dual purpose of providing flood protection by collecting storm water runoff and acting as a preliminary filter by removing suspended solids. This $222,500 project is part of the National Estuary Program.

Five communities in South Dakota have received CW-SRF loans for wetlands projects. The communities of Clear Lake, Huron, Lake Cochrane, Pickerel Lake, and Richmond Lake have used CW-SRF loans to construct wetlands as part of improvements to their publicly owned treatment works (POTW). Constructed wetlands are a complex of saturated substrates, emergent and submergent vegetation, animal life, and water that simulates natural wetlands for various benefits. In these cases, the wetlands follow a lagoon treatment system to further reduce pollutant levels in the wastewater prior to discharge. User charges are being used to repay the loans, which total about $7.5 million for all five communities.

Conservation Reserve Program (CRP)

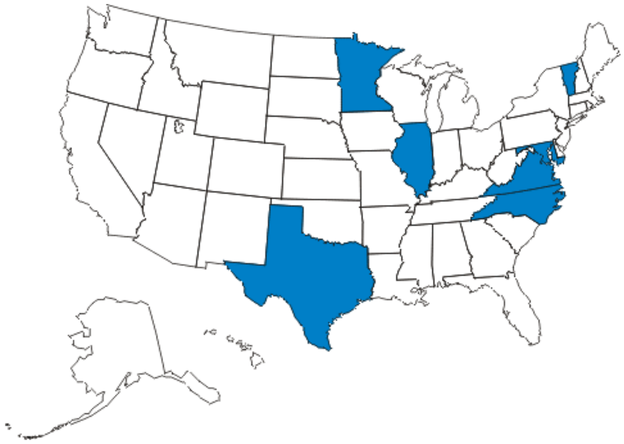
The CRP is based on the premise that financial incentives make conservation buffers economically attractive. Annual rental payments are based on the relative productivity of the soil type being offered and the average dryland cash rental rate for comparable land in the county. A 20 percent incentive is added to the annual rental rate for field windbreaks, grassed waterways, filter strips, and riparian buffers. A 10 percent incentive is added to the annual rental rate for land within designated wellhead protection areas.

Cost-sharing payments up to 50 percent of the cost of establishing a permanent cover are provided. Some of the measures eligible for cost sharing are site preparation, temporary cover until permanent cover is established, grading or shaping, seeds, trees or shrubs, plastic mulch, and supplemental irrigation or fencing.

Contracts under the continuous CRP sign-up are 10 to 15 years in length, depending on the approved practice. Annual rental payments are made after October 1 each year and cost-share payments are made when the approved practices are completed.

Source: NRCS, 2000a.

Table 6-1. Effectiveness of Vegetated Filter Strips for NPS Pollutant Removal



Measurements taken throughout the United States show the NPS pollutant removal capabilities of vegetated filter strips. The studies show variabilities in NPS pollutant removal capabilities for various VFS lengths and vegetative cover types. Results of studies in various states (see map at left) are shown in the table below. Additional information about each study cited in the table is provided in Appendix F.

Study Nutrient removal by forested and grassed vegetated filter strips **Vegetation** cottonwood/silver maple reed canary grass **VFS Length (ft)** 53, 128 **N** 90%, 90% **Study Title** Embarras River, Illinois
Study Pollutant removal by vegetated filter strips under channelized and overland flow conditions **Vegetation** Mixed fescue/alfalfa foxtail **VFS Length (ft)** 300, 200, 500-1500 **TSS** 73%, 63%, 78% **N** 80/86%[1], 71/72%[1], 81/85%[1] **P** 78% **Study Title** University of Illinois, Illinois
Study Removal of sediment and nutrients by vegetated filter strips **Vegetation** bare plots **VFS Length (ft)** 15 **TSS** 66% **N** 0% **P** 27% **Study Title** Chesapeake Bay, Maryland
Study Pollutant removal by vegetated filter strips **Vegetation** corn, orchard grass, sorghum, oats, average **VFS Length (ft)** 115-135 **TSS** 86%, 66%, 82%, 75%, 79% **N** 84% **P** 83% **Study Title** Stevens County, Minnesota
Study Retention of sediment and nutrients by grassed filters and riparian buffers **Vegetation** grass **VFS Length (ft)** 13 **TSS** 50% **Study Title** Coastal Plain/Piedmont, North Caroliina

Study Pollutant removal from highway runoff by vegetated buffer strips, U.S. 183
Vegetation Prairie buffalo grass
VFS Length (ft) 24-30
TSS 87%
N 50%
P 44%
Study Title Austin, Texas

Study Pollutant removal from highway runoff by vegetated buffer strips, Walnut Creek
Vegetation mixed grasses
VFS Length (ft) 22-27
TSS 85%
N 23%
P 34%
Study Title Austin, Texas

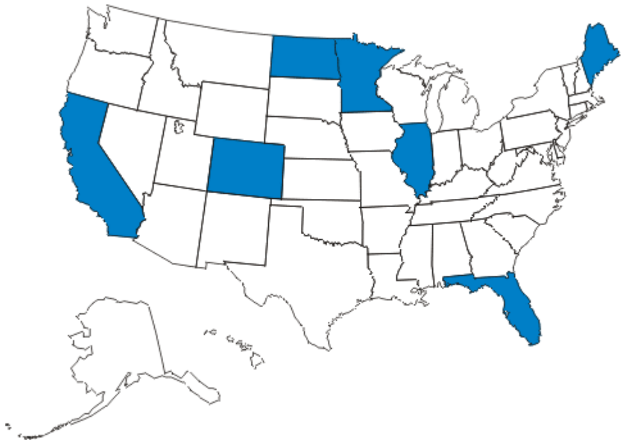
Study Removal of sediment and nutrients by vegetated filter strips
Vegetation orchard grass
VFS Length (ft) 15, 30
TSS 81%, 91%
N 64%, 74%
Study Title Blacksburg, Virginia

Study Nutrient removal by vegetated filter strips
Vegetation orchard grass
VFS Length (ft) 15, 30
TSS 70%, 84%
N 54%, 3%
P 61%, 79%
Study Title Prices Fork Research Farm, Virginia

Study Pollutant removal from runoff by a vegetated filter strip
Vegetation fescue, ryegrass, bluegrass
VFS Length (ft) 85
TSS 95%
N 92%
P 89%
Study Title Charlotte, Vermont

VFS, vegetated filter strip; TSS, total suspended solids; N, nitrogen; P, phosphorus.
[1]Total Kjeldahl nitrogen/ammonia nitrogen.

Table 6-2. Effectiveness of Constructed Wetlands for NPS Pollutant Removal



Measurements taken at several locations in the United States show the NPS pollutant removal capabilities of constructed wetland systems. Results of studies in various states (refer to map graphic) are shown in the table below. Additional information about each study cited in the table is provided in Appendix F.

Study Pollutant removal from urban runoff by a subalpine constructed wetland **TSS** 85% **N (total)** 85%-90% **P (total)** 47%[1], 20%[2] **Metals** 84% (Fe) **Study Title** Lake Tahoe, California
Study Suspended solids and phosphorus removal from storm water runoff by a wetland system **TSS** 70% **P (ortho)** 52% **Metals** 34% **Study Title** Shop Creek Pond, Colorado
Study Phosphorus and nitrogen removal in a subtropical constructed wetland **P (total)** 72% **Study Title** Kissimmee River, Florida
Study Suspended solids and nutrient removal in a sediment filtration and constructed wetland system **TSS** 94%, 96%[3] **N (total)** 76% **NH_3** 37% **NO_3** 70% **NO_2** 75% **P (total)** 90% **P (ortho)** 78% **Study Title** Lake Jackson, Florida
Study Pollutant removal from urban runoff in a detention pond/wetland system **TSS** 55% **N (total)** 36% **P (total)** 43% **P (ortho)** 21% **Metals** 83% (Pb), 70% (Zn) **Study Title** Orange County, Florida

Study	Pollutant removal from highway runoff by a constructed wetland system
TSS	55%-83%
N (total)	36%
P (total)	43%
Metals	55%-83%, (Pb, Zn)
Study Title	Orlando, Florida
Study	Pollutant removal from residential and golfcourse runoff by wetland impoundment
TSS	50%
NO_2	71%
P (total)	62%
Study Title	Palm Beach Gardens, Florida
Study	Pollutant removal from urban stormwater runoff in a detention pond/wetland system
TSS	71%
NH_3	44%
NO_3	75%
NO_2	75%
P (total)	47%
P (ortho)	56%
Study Title	Tampa, Florida
Study	Pollutant removal from agricultural and urban runoff by constructed wetlands
TSS	86%-90%
N (total)	61-92%
P (total)	65%-78%
Study Title	Des Plaines River, Illinois
Study	Pollutant removal from agricultural runoff by a constructed wetland system
TSS	95%-97%
P (total)	82%-91%
Study Title	Long Lake, Maine
Study	Phosphorus and sediment removal from agricultural runoff by wetland treatment system
TSS	95%
P (total)	92%
Study Title	St. Agatha, Maine
Study	Phosphorus removal from urban and agricultural runoff by constructed wetlands
P (total)	39%
Study Title	Clear Lake, Minnesota
Study	Water quality improvements by a combined detention/wetland storm water treatment facility
TSS	96%
N (total)	74%
NO_3	63%
TKN	76%
P (total)	78%
Metals	90% (Pb)
Study Title	Lake McCarrons, Minnesota
Study	Pollutant removal from storm water by a constructed wetland
P (total)	40%
Study Title	Spring Creek, North Dakota

TSS, total suspended solids; N, nitrogen; NH_3 ammonia; NO_3, nitrate; NO_2, nitrite; TKN, total kjeldahl nitrogen; P, phosphorus; Fe, iron; Pb, lead; Zn, zinc.

[1]Particulate phosphorus.

[2]Soluble phosphorus.

[3]Organic TSS.

Table 6-3. Nitrate-N Concentration Reduced by Forested Riparian Areas and VFS

Forested Sites
Location Lake Tahoe **Length (m)** 285[1] **Ground-water** 99%[2] **Author, Year** **(as cited in Martin, 1996)** Rhodes et al., 1985
Location Maryland **Length (m)** 197 **Ground-water** 95% **Author, Year** **(as cited in Martin, 1996)** Jordan et al., 1993
Location Georgia **Length (m)** 180 **Ground-water** 83% **Author, Year** **(as cited in Martin, 1996)** Lowrance et al., 1984
Location Maryland **Length (m)** 164 **Ground-water** 90% **Surface Water** 60% **Author, Year** **(as cited in Martin, 1996)** Peterjohn and Correll, 1984
Location Rhode Island **Length (m)** 82-197 **Ground-water** >80% **Surface Water** **(as cited in Martin, 1996)** Simmons et al., 1992
Location North Carolina **Length (m)** 154 **Ground-water** >99% **Author, Year** **(as cited in Martin, 1996)** Jacobs and Gilliam, 1985b
Location Iowa **Length (m)** 66 **Ground-water** 83%[3] **Author, Year** **(as cited in Martin, 1996)** Schultz et al., 1995
Location Great Britain **Length (m)** 66 **Ground-water** 99% **Author, Year** **(as cited in Martin, 1996)** Haycock and Pinay, 1993
Location Iowa **Length (m)** 66 **Ground-water** 96% **Author, Year** **(as cited in Martin, 1996)** Licht and Schnoor, 1991
Location Maryland **Length (m)** 62 **Ground-water** 93% **Surface Water** 79% **Author, Year** **(as cited in Martin, 1996)** Peterjohn and Correll, 1984

Forested Sites (continued)
Location North Carolina **Length (m)** 53 **Ground-water** >99% **Author, Year** **(as cited in Martin, 1996)** Jacobs and Gilliam, 1985b
Location North Carolina **Length (m)** 49 **Ground-water** 96% **Author, Year** **(as cited in Martin, 1996)** Hubbard and Sheridan, 1989
Location North Carolina **Length (m)** 33 **Ground-water** 99% **Author, Year** **(as cited in Martin, 1996)** Xu et al., 1992
Location New Zealand **Length (m)** 16 **Ground-water** 98% **Author, Year** **(as cited in Martin, 1996)** Schipper et al., 1989
Location Maryland **Length (m)** 12 **Surface Water** 95%[4] **Author, Year** **(as cited in Martin, 1996)** Doyle et al., 1977
VFS (Grass) Sites
Location Great Britain **Length (m)** 53 **Ground-water** 84% **Author, Year** **(as cited in Martin, 1996)** Haycock and Pinay, 1993
Location Virginia **Length (m)** 30 **Surface Water** 73%[4] **Author, Year** **(as cited in Martin, 1996)** Dillaha et al., 1989
Location Virginia **Length (m)** 15 54%[4] **Author, Year** **(as cited in Martin, 1996)** Dillaha et al., 1989
Location Maryland **Length (m)** 13 **Ground-water** **Surface Water** 68%[4] **Author, Year** **(as cited in Martin, 1996)** Doyle et al., 1977

[1]Estimated based on given area.
[2]Measured using mass balance.
[3]Measured in soil water.
[4]Total nitrogen reduction.

Table 6-4. Costs and Economic Benefits Associated with Vegetative Treatment Systems

Examples from throughout the United States show the expected cost of many types of VTS as well as their value to the respective communities. For some of these projects, the value of the VTS is based on the dollar value saved from not using the structural or conventional approach. The cost to install structural or conventional technologies to replace the functions of constructed wetlands, buffers, and vegetated filter strips are shown to be much greater than the actual cost of the vegetated treatment systems. Results from studies in various states (refer to map graphic) are shown in the table below. Additional information and references about each study is provided in Appendix F.

Description Installation of stream buffers and riparian zones **Vegetated Treatment Systems** $6,600 (CRP rent: $150/acre times 44 acres) **Estimated Benefit to Community** Exclusionary fencing keeps cattle out of stream, and filters and buffers help protect and improve water quality. **Study Title and State/Tribe/Agency** Allamakee County, Iowa
Description Valuation of creating vegetative filter strips for reducing water treatment costs **Vegetated Treatment Systems Project Costs** $803 to $10,522 per acre **Estimated Benefit to Community** $2.7 million per year (based on 25% sediment reduction). **Study Title and State/Tribe/Agency** Middle Raccoon Watershed Partnership, Iowa
Description Establishment of filter strips along waterways **Vegetated Treatment Systems Project Costs** $26,000 worth of switchgrass seed given to farmers **Estimated Benefit to Community** Installation of filter strips will remove chemicals and sediment and lead to improved water quality. **Study Title and State/Tribe/Agency** Iroquois County, Illinois
Description Addition of best management practices (BMPs) through the Skaneateles Lake Watershed Agricultural Program **Vegetated Treatment Systems Project Costs** $150,000 **Estimated Benefit to Community** BMPs will help improve farm planning and nutrient management to improve water quality. **Study Title and State/Tribe/Agency** Onondaga Soil and Water Conservation District, New York
Description Structural versus nonstructural shore erosion/control approaches **Cost of Conventional Project** **(without VTS)** $3.7 million to $4.3 million per year **Vegetated Treatment Project Costs Systems** $1.6 million per year **Estimated Benefit to Community** $1.5 million to $2.1 million per year. **Study Title and State/Tribe/Agency** Chesapeake Bay, Maryland
Description Restoration of Ronan Spring Creek **Vegetated Treatment Systems Project Costs** $5,000 for shrubs **Estimated Benefit to Community** Stream restoration, through dredging and deepening, will bring back fish habitat and backwaters for waterfowl. **Study Title and State/Tribe/Agency** Confederated Salish and Kootenai Tribes, Montana
Description Valuation of local agricultural benefits from riparian improvement from 25% reduction of sediment **Estimated Benefit to Community** $2.7 million in treatment costs. **Study Title and State/Tribe/Agency** Ohio State University Extension Service, Ohio

Figure 6-1. Example of Vegetated Filter Strip

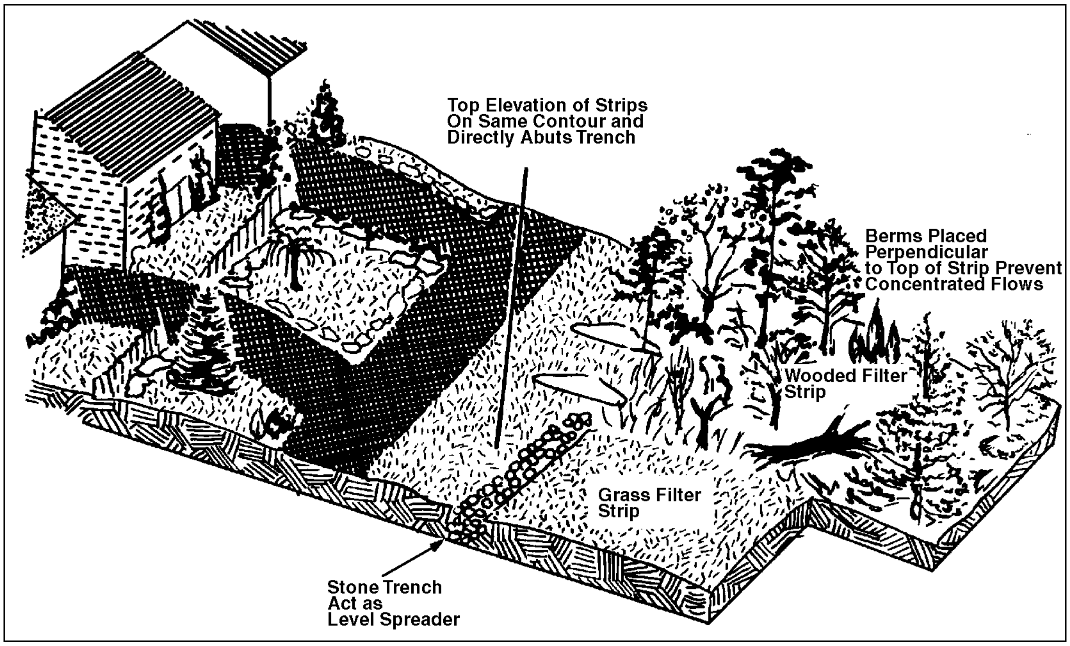


Figure 6-2. Example of Constructed Wetland